ANALYSIS OF CERAMIC COLOR BY SPECTRAL REFLECTANCE

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DO NOT CITE IN ANY CONTEXT WITHOUT PERMISSION OF THE AUTHORS

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Radiometric and visual techniques are compared as quantitative methods for determining pottery color. An analysis of fifty-two prehistoric sherds selected at random from a multicomponent site indicates that there is an increase in the accuracy and efficiency in determining color using a spectroradiometer over subjective visual observations. Further, radiometric data can be transformed to CIE chromaticity coordinates and Munsell color from spectral reflectance curves and analyzed directly to access quantitative accuracy. The color, or spectral reflectance, of filter paper samples and a subset of the sherds measured by a standard field radiometer were strongly correlated with measurements of color derived from a low-cost PC-based color sensor traditionally used in graphic arts applications. Radiometric data were compared with visual observations of Munsell color conducted by two archaeologists. The two methods were most similar in estimates of value and chroma. The human observers differed widely in their estimates of hue. The radiometric approach provides more consistent and exact measurements of color than does visual observation, providing archaeologists with an efficient, effective, and potentially a low-cost method to determine an important common attribute of artifacts.

La técnica radiométrica y la técnica visual son comparadas como métodos cuantitativos para determinar el color de artefactos hechos de barro (alfarería). Un análisis de cincuenta y dos (52) pedazos de piezas prehistóricas (seleccionadas al azar de un campo con multitud de componentes) indica que el espectroradiómetro, comparado con el método visual, produce medidas de color con mucha más eficacia y exactitud. Más aún, datos radiométricos pueden ser transformados a coordinadas cromáticas CIE y las curvas de reflectancia espectral pueden ser transformadas a color Munsell y analizadas directamente obteniendo así exactitud cuantitativa. Datos radiométricos son comparados con observaciones visuales (expresadas en color Munsell) dirigidas por dos arqueólogos. Ambos métodos producen estimados similares con respecto a valor y croma. El método visual produce observaciones más confiables con respecto al tinte (tono del color), la caractéristica del color al cual el ojo humano es más sensitivo. Medidas de color (reflectancia espectral) obtenidas con un radiómetro de campo standard fueron altamente correlacionado con medidas de color obtenidas de un sensor de color de los tradicionalmente usados en aplicaciones de artes gráficas. El método del radiómetro es consecuente y produce medidas de color más exactas que el método visual, por lo que provee a los arqueólogos de un método --eficiente, efectivo, y posiblemente de bajo costo-- para determinar un atributo común e importante de los artefactos arqueológicos.

Quantitative, repeatable measurements are essential for a meaningful analysis and classification of artifacts. Color is frequently used as a key variable to classify artifacts, particularly ceramics. Color can provide a trained investigator important information of the temporal, cultural and functional aspects of a ceramic industry. The differences in color observed among ceramic sherds result primarily from variance in clay composition, atmosphere, temperature, and duration of firing (Shepard 1956:103; Rice 1987:333-334). In addition, the color of sherds recovered from archaeological contexts may be the consequence of use (staining, deposition of carbons during cooking) and of post-depositional events (leaching of soil water, erosion, accidental reheating) (Shepard 1956: 103).

The primary method used by archaeologists to measure the color of prehistoric ceramics is visual comparison with the Munsell® Soil Color Chart (Macbeth Division of Kollmorgen Instrument Corporation). Shepard (1956:107) states that "[t]he advantages of the Munsell system are so great that it is hardly necessary to argue its superiority". She goes on to argue that "[c]olor reporting with the Munsell system is a means of translating to common symbols the color perception on which we rely in pottery classification…a standard of this kind aids in making reliable comparisons and meaningful interpretations" (Shepard 1956:113). Applications of the Munsell color system have been found useful in the study of Pueblo and Maya pottery. In the Southwestern US, a study of Rio Grande-paint

wares using the Munsell terminology, provided some correlation between tempering and color (Shepard 1956:154-155). The Munsell color system is often utilized as part of the standard description of prehistoric pottery from the Southeastern U.S. (Luer 1996:181-191; Jurney and Perttula 1995: 23, Tables 1 and 2) and Europe (Maniatis et al. 1984: 207-208). In the latter study, a sample of Punic amphoras was divided into meaningful groups on the basis of Munsell color descriptions, which augmented the results of additional physico-chemical techniques. Several recent studies have utilized a suite of highly quantitative, physical and chemical techniques on ceramics to address important archaeological issues such as trade, raw material sources and firing technology (Bishop et al, 1988; Steponaitis et al, 1996). In the former study, the color of Hopi yellow-ware is measured using a tristimulus chromameter and then converting the results into the Munsell notation (Bishop et al 1988:328). Highly sophisticated techniques such as Mossbauer spectroscopy and gamma ray analysis (Crenshaw et al 1985) have been used in archaeology, because color is an indirect measure of the mineral constituents of clay, such as ^{57}FE and other colorants in the ceramic body. Still, the Munsell system is the most widely used approach by archaeologists to analyze color in artifacts. The ability to increase the reliability of this standardized color measurement approach, and do so efficiently and easily, can contribute greatly to the analysis of artifact color. Color measurements through spectral

reflectance provide increased accuracy and reliability, similar to that currently possible using other physico-chemical methodologies. The use of a radiometer, and its less expensive counterparts, promises to add valuable information on the optical properties of artifacts, and offers exciting prospects for expanding this type of analysis into the non-visible (i.e. infrared, thermal and ultraviolet) portions of the electro-magnetic spectrum (EMS).

When using the Munsell system analysts must ensure that observations are made by the same person under similar, preferably solar, illumination (Rice 1987: 343) and constant viewing geometry. Since these conditions are often difficult to control, this method may produce highly variable results. Differences in observers' skill, their physiological distinctions, and the variations resulting from slight changes in the geometry of illumination and observation between observations result in variable, non-replicable results.. Therefore, the development of a reliable, objective, and non-destructive method for the measurement of artifact color could serve as a significant tool in archaeological studies. This contention should be particularly true for the technique proposed herein that allows objective, efficient and replicable measurements of color that further standardize color analysis of artifacts utilizing the Munsell color scheme.

The method presented in this report is based on standard spectroradiometric techniques wherein a spectroradiometer (in this case a LI-COR 1800) is used to

measure pottery reflectance in the 380-790 nm wavelength range of the EMS. Selected samples of the Munsell color chips were also scanned with the radiometer to determine the efficacy of the spectroradiometric procedure. This new technique was then compared with the results of visual observations made on the same samples by two archaeologists. Finally, reflectance of color filter papers taken with the LI-COR 1800 spectroradiometer were compared with those taken on the same samples using a Colotron II, a low-cost digital color sensor to assess the latter's applicability to archaeological research. A small subset of ceramics from the Jackson Landing site were also scanned with the Colotron II to assess if the results observed when scanning colored particles on filter paper applied to sherds.

METHODS

Fifty-two sherds, representing a 20 per cent sample of the ceramics excavated in 1989 from the Jackson Landing site (22HA515), in Hancock County, Mississippi, (Giardino and Jones 1996) were randomly selected for color analysis. These ceramics date from both the Late Marksville (AD 200-400) and Mississippian (AD 1200-1500) periods although, sherds for this study were drawn from the collection without regard to provenience since there was no intent, at this time, to test any spatio-temporal hypothesis relating to sherd color. Rather, the sample was

selected to provide a representative range of colors found throughout the entire, excavated ceramic collection.

Spectroradiometers are instruments that measure radiometric quantities as a function of wavelength (Wyszecki and Stiles 1982: 229). When reflected radiant energy is normalized to incident illumination the spectral reflectance of an object can be determined. Color is derived from the maximum, or dominant, spectral energy reflected from an object. Hence, color can be defined quantitatively from reflectance spectra. For this study, the spectral reflectance (i.e., color) of each sherd and select Munsell color chips was measured in the laboratory using a scanning spectroradiometer with microscope attachment (Model LI-1800UW; LI-COR, Inc. Lincoln NE). The reflectance spectra were converted to CIE (Commission Internationale de I'Eclairage) chromaticity coordinates. The CIE is a method to define color through a numerical specification based on the additive mixture of primary colors yielding a three-dimensional color space consisting of X,Y,Z coordinates. These coordinates or tristimulus values are calculated using the spectral distribution of the light source, the spectral reflectance of the object scanned and the human color matching functions x, y, and z (Wyszecki and Stiles 1982:131). Additionally, the X,Y, Z coordinates can be transformed, through a linear approximation into x,y,Y coordinates representing an *h*-ellipsoid space (Wyszecki and Stiles 1982:207). During this experiment, the x,y,Y coordinates

were computed for each sherd.

The Munsell Color System is frequently used in archaeological analysis, particularly in measuring the color of stratigraphic soil profiles, textiles and pottery. There are 10 hues in the Munsell system, each subdivided into 10 segments. The hue notation of a color indicates its relation to red, yellow, green, blue and purple. The value attribute ranges from 0 (black) to 10 (white) and contains nine evenly spaced shades of gray. In general, Hue indicates the lightness of a color. Chroma is an open ended scale that indicates a color's strength or departure from neutral (Committee on Colorimetry, Optical Society of America, 1966:334-336; Wyszecki and Stiles 1982:507-509). The Munsell Color System was derived from the color designations of standard objects based on the observations of several thousand observers. The number of colors represented in the Munsell system is well below that discernible by the human eye which has been estimated at about ten million (Wyszecki 1989:824).

For this study, the surface of sherds, previously washed with water to remove soil particles, were illuminated by a 300 W tungsten lamp and scanned at five nm intervals from 380 nm (ultraviolet) to 790 nm (near infrared). At each wavelength interval, the radiance reflected from a sherd was divided by the radiance reflected from a white reference (Spectralon SRT-99-05, Labsphere, Inc., North Sutton, NH) to derive reflectance for each sherd. Each scan required approximately 15

seconds to complete. Three scans each of the reference and sherd were averaged to compensate for possible fluxes in the light source. Each sherd was placed at a distance from the spectroradiometer to fill the microscope's field-of-view and on an area of the sherd that was most representative of the dominant sherd color. Following the scans, the area on each sherd was outlined in pencil to assure that the human observer measured the identical place on each sherd's surface. The spectral reflectance for each sherd was converted to 1931 2° observer CIE chromaticity coordinates. Using the x,y, and Y values computed for each sherd, the Munsell equivalent was computed using a PC-based CIE-to-Munsell conversion program (version 7.1, Macbeth Division of Kollmorgen Instruments Corporation). The total time required to convert the reflectance values to Munsell notation is less than five seconds per sherd. A select set of Munsell color chips were scanned using the same procedure used for scanning the sherds. The reflectance spectra obtained for the color chips were converted to the 1931 2° CIE chromaticity coordinates and then to Munsell notation (such as 7.5YR 6/8) as was done for the sherds.

In general, field radiometers, such as the LI-COR 1800, are expensive (between $15,000-$20,000) and require trained operators. To test whether radiometry can be used routinely by most archaeologists, data acquired using the LI-COR 1800 were compared to an inexpensive color sensor (Colortron II Light Source, Inc.,

Larkspur, California). The Colortron II is a low cost, computer-based (Macintosh) color sensor, traditionally used in graphic arts applications with a spectral range of 390 to 700 nm (i.e. the visible portion of the spectrum). The instrument uses a diffraction grating with 45° illumination geometry and 10 nm spectral bandwidth. Because the twin tungsten lamps are internal, the scanning system is entirely enclosed and not affected by external lighting conditions. A white calibration standard, unique to the instrument, and a black box (0 per cent reflectance) are scanned to calibrate the instrument. The Colorton II is placed directly over the target to be scanned. Each scan requires about 10 seconds to scan a three mm^2 area. The reflectance spectra are recorded directly on the computer and converted to the specified color spaces or parameters (CIE, XYZ, CIE xyY, Hue/Saturation/Brightness, RGB, optical density) using vendor-supplied software. The Colotron II, developed originally for desktop publishing, is used by professional artists for accurate mapping of color. It has the ability to determine true color by reflectance.

Finally, two archeologists were asked to identify the Munsell color chip which matched most closely the visual color of the area scanned by the radiometer. Sherds and Munsell chips were viewed under diffuse sunlight and constant viewing angle.

RESULTS AND DISCUSSION

There was a high degree of correlation between estimates of Munsell Color obtained from scans of the Munsell chips using the LI-COR spectroradiometer and the reported Munsell System parameters. Pearson correlation coefficients (r) were .91, .99, and .98, for hue, value and chroma, respectively (n = 20). The Munsell notations are based on the visual observations of expert colorists and measurements with the General Electric Recording Spectrophotometer at the Massachusetts Institute of Technology and the National Bureau of Standards (Hardy 1929; 1935; Macbeth Division of Kollmorgen Instrument Corporation, 1994). Hence, the spectroradiometer employed during this study provided estimates in direct agreement with the accepted standard of color definition. Therefore, estimates of sherd color of the 52 samples obtained using this method should closely match the color offered by expert colorists.

The LI-COR spectroradiometer is an expensive and delicate instrument. To provide archaeologists with a less costly and field-adapted tool, the LI-COR results were compared to the spectral reflectance and CIE coordinates obtained using the Colortron II color sensor. Several filter papers containing colored particles filtered from water samples were scanned by each instrument and data converted to percent reflectance. A representative comparison of the reflectance spectra is shown in Figure 1. There is good agreement between the reflectance or

color measured by the two instruments over the entire visible spectrum. The greatest difference is in the blue-green region where scattering may have affected the LI-COR data. Estimates of Munsell color derived by the two instruments were strongly correlated (r > .99 for Hue, Value, and Chroma). A dozen sherds from the Jackson Landing sample were scanned with the Colotron II to assess its ability to measure pottery color. The results agreed closely with those measured by the LI-COR, and were consistent with the results obtained when both instruments were used to scan colored particle paper.

Estimates of Munsell color values can vary significantly between human observers. Based on the results above, estimates of Hue, Value, and Chroma for the 52 sample sherds derived from the LICOR measurements were regarded to be the *true* Munsell system values. There was reasonably good agreement between the study's two archaeologists in estimating the lightness (Munsell Value, r=.81) and saturation (Munsell Chroma, r=.85) of a sherd while there was little agreement as to a sherd's Hue (r=.44). Further, there was no consistent evidence as one observer providing more accurate estimates of color (Table 1) or correlation with the LI-COR results. Color sensations reported by an observer with normal color vision vary as a function of the wavelength of the stimulus; hue is the color we perceive, based on the dominant wavelength reflected from a surface (Mather 1987 :157, 227). Numerous studies have noted considerable

variation between observers in experiments on hue discrimination (see for example, Wasserman 1978 and Overheim and Wagner 1982). The causes of these differences are beyond the scope of this report.

SUMMARY AND CONCLUSION

Any cultural trait that can be objectively and consistently quantified can provide valuable information for typology and classification. For example, the color of Native American pottery is a function of the technology and materials used as well as the potters stylistic and aesthetic preferences. As such, pottery color is a trait that may be meaningful to cultural and temporal differentiation between prehistoric ceramic industries. When measured objectively, the co-occurrence of specific colors with other ceramic traits, such as paste and decoration, furthers the development of ceramic types and varieties. Finally, the relationship between specific ceramic colors and variable manufacturing and firing techniques is well documented (Shepard 1956; Rice 1987) Quantifying ceramic color may lead to a better understanding of the state of ceramic production among pre-industrial groups. However, because there can be considerable variation in the perception of an object's color among observers, a method is needed that will provide reliable, consistent quantitative results.

Reliable measurement of color in prehistoric artifacts, especially in ceramic analysis, yields data for better understanding issues related to archaeological theory and method. Certainly, studies of artifacts that have utilized the Munsell system (see above) should benefit from the radiometric approach, resulting in accurate and consistent measurements. In describing the results of their analysis using a tristimulus chromameter, Bishop et al (1988:328) list several advantages of their measurement technique over the direct use of the Munsell charts. Specifically, their approach standardizes color measurements, eliminates errors resulting from variable lighting conditions, is reproducible, and it can deal systematically with colors that fall between the Munsell color chips (Bishop et al 1988:328). Color analysis using spectral reflectance extends the capability of researchers to measure color beyond that of the chromameter, and allows more detailed statistical manipulation and graphing of results.

The objective measurement of color can be used to refine ceramic classifications, particularly those that rely on color. For example, Phillips (1970:47-57) notes that the classification of Baytown Plain vessels into varieties has been a difficult task for Southeastern archaeologists. Baytown Plain variety descriptions are often predicated on the covariation of attributes that includes color. In some cases, such as the distinction between Baytown Plain *var. Valley Park* and Baytown Plain *var. Vicksburg* , gray surface color is a defining trait shared by both varieties. Quantitative measurement of color using a spectroradiometer can be used to quickly analyze these distinctions and refine the classification.

The proposed radiometric methodology significantly enhances those important analyses where pottery color is identified as significant mode in spatio-temporal studies. For example, Nance (1976:229) reporting on the ceramics from the Durant Bent site in Alabama, found that "[t]he ceramic attributes systematically studied in the mound ceramic sample which showed consistent trends through the sequence were surface finish (plain vs. check stamped) and paste color" . Nance utilizes the Munsell system to classify paste color and to resolve issues related to inter-level mixing through a site sequence (1976: 231). Radiometric measurements applied to this and other similar collections can be used to test these types of observations, more accurately and more thoroughly.

Even though color does not afford an accurate key to the chemical composition of clay, the accurate measurement of color leads to direct evidence of firing conditions, and indirect inference of significant clay characteristics such as the amount, distribution and particle size of iron oxide (Shepard 1956:103). By measuring the color of refired chips with a spectroradiometer, or its less-costly counterparts, archaeologists can determine whether sherds were fully oxidized. "The color of fully oxidized paste affords a useful criterion of classification, which has yet been little exploited" (Shepard 1956: 103,105). These results can be combined with research on the chemical composition of pottery (see for example, Steponaitis et al, 1996: 555-572) to yield more insightful analyses on how color covaries with clay composition, manufacturing techniques and sources of raw materials (see Shepard 1956: 154-5 for example of how temper affected color in Rio Grande Glaze paint pottery).

The study of Mayan redware provides another example of the potential use of standard, reliable color measurement of pottery samples, especially those that are predominated by plain sherds. The early redware, Joventud, seems to grade subtly into the succeeding Sierra Reds. But body sherds are often hard to sort. Also, there is some contention that the later "slatewares" can be divisible into eastern and western groups on the basis of paste (red versus brown) (Ringle personal communication 1997). Accurate color measurements, reported either as CIE

coordinates, Munsell designation or spectral curves, should provide the necessary data to resolve these archaeological issues.

Application of methodology proposed in this report extends beyond the study of ceramics. Color is an important component of most other prehistoric remains, such as murals, lithics and textiles. As an example, Paul (1990) used the Munsell system to study the color of fabrics from the Paracas Necropolis located on the south coast of Peru. She determined, from the analysis of color, that "the artists who made these ancient Peruvian textiles shared principles of design, concepts of order, procedures of manufacture and a body of technical knowledge" (Paul 1990:20). She goes on to assert that" one of the important findings of [her] study is that a combination of distinctive color features characterizes Paracas Necropolis garments and is critical to the definition of the textile style" (Paul 1990:20). In these types of cases, the analysis of color through measured reflectance should provides significant refinements in data collection and analysis.

The results of this study have shown that a spectroradiometer can provide accurate estimates of the color of ceramic artifacts from archaeological sites. A spectroradiometer yields numerical data which can be analyzed statistically, and converted to various color scales such as the CIE and Munsell color systems. Artifact color can ultimately be represented as spectral curves, allowing more detailed and accurate inter-artifact comparisons. A spectroradiometer can provide objective measurements largely uncoupled from scientific and analytical experience. Data acquisition and analysis is fast and efficient. Inexpensive alternatives such as the Colotron II color sensor can widely extend this method to most archaeologists for measurements of color in the field and laboratory. More systematic experimentation are needed to fully test the reliability of the Colotron II for analyzing artifact color. However, the measurements obtained with the Colotron II during this study on a small subset of sherds from Jackson Landing indicate that the low-cost alternative will provide results that correlate strongly with those taken with the radiometer.

The ability to quantify color as an aspect of ceramic classification adds a ubiquitous and highly diagnostic trait to the arsenal of the ceramic typologist. Color is important in the study of ancient ceramic technology and in the study and identification of ancient ceramic sources. The quantitative analysis of color may contribute to the refinement of cultural chronologies. Similar studies (Bishop et al 1988) have illustrated how accurate measurement of physical variables in ceramics improves artifact description, and identifies variation across several dimensions, and provides a means for archaeologists to assess the significance of the observed variability.

Additional analyses of larger samples of ceramics from different periods and geographical locations are required to ascertain the utility of quantitative color measurements in deriving temporal and cultural ceramic modes. More work is needed also on those sherds whose surface colors are highly variable to determine if "color combinations" are meaningful categories of measurement. Further, radiometric measurements of the external and internal surfaces and the core of ceramic artifacts must be completed systematically so that the co-occurrence of color traits in single sherds can be quantified and compared with other sherds.

These additional issues, and other not yet explored, offer opportunities for the application of reflectance techniques to archaeological field work, laboratory analysis and artifact classification. The process described here for deriving quantitative spectral reflectances from prehistoric pottery provides to archaeologists the ability to measure a commonly occurring artifact trait in a consistent, efficient and objective way. In addition, the spectroradiometers' capability to measure reflectance of artifacts in non-visible wavelengths may provide archaeologists with a new and mostly unexplored methodology for artifact and site analysis. Spectral curves derived in the ultra-violet and infrared portions of the EMS may yield data that reveals meaningful patterns of color in artifacts, in some ways analogous to the discoveries made using infrared and thermal remote sensing for classifying landscapes.

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REFERENCES CITED

Bishop, R.L.; V. Canouts, S. De Atley, A. Qöyawayma, and C.W. Aikins

1988 The Formation of Cermaic Analytical Groups: Hopi Pottery Production and Exchange, A.C. 1300-1600. *Journal of Field Archaeology* Volume 15 (3): 317-338.

CIE⇔Munsell Conversion Program, Version 7.1

1987 Macbeth Division of Kollmorgen Instruments Corporation, New Windsor, NY.

Committee on Colorimetry, Optical Society of America

1963 *The Science of Color*. Optical Society of America, Washington, DC.

Cranshaw, T. E., Dale, B. W., Longworth, C. O. and Johnson, C. E.

1985 *Mössbauer Spectroscopy and its Applications.* Cambridge Univ. Press.

Giardino, Marco J. and Robert Jones III

1996 Archaeological Excavations at the Jackson Landing Site, Hancock County, Mississippi. Unpublished manuscript on file with the Earth System Science Office, NASA, Stennis Space Center, Mississippi.

Hardy, A.C.

1929 A Recording Photoelectric Color Analyser. *J Opt Soc Am and RSI*, 18, :96-117.

Hardy A.C.

1935 A New Recording Spectrophotometer. *J Opt Soc Am,* 25. :305-311.

Jurney, David H. and Timothy K. Perttula

1995 Nineteenth-century Alibamu- Koasati Pottery Assemblages and Culinary Traditions. *Southeastern Archaeology*, 14(1): 17-30.

Kuzio, Rachel E.

1996 Colorimetry of Pottery Sherds. Unpublished manuscript on file with the Earth System Science Office, NASA, Stennis Space Center, MS.

Luer, George M.

1996 Mississippian Ceramic Jars, Bottles, and Gourds as Compound Vessels. *Southeastern Archaeology* 15(2): 181-191.

Maniatis, Y; R.E. Jones, I.K. Whitbread, A. Kostikas, A. Simopoulos, Ch. Karakalos, and C. K. Williams, II

1984 Punic Amphoras Found at Corinth, Greece: an Investigation of Their Origin and Technology. *Journal of Field Archaeology* 11(2):205-222.

Mather, Paul

1987 *Computer Processing of Remotely Sensed Images: An Introduction.* John Wiley and Sons, New York.

Munsell® Soil Color Charts

1994 Macbeth Division of Kollmorgen Instruments Corporation, New Windsor, NY.

Nance, C. Roger

1976 Artifact Attribute Covariation as the Product of Inter-level Site Mixing. *Midcontinental Journal of Archaeology* 1(2): 229-231.

Overheim, R. D. and D. L. Wagner

1982 *Light and Color.* Wiley and Sons, New York.

Paul, Anne

1990 The Use of Color in Paracas Necropolis Fabrics: What Does it Reveal about the Organization of Dying, Designing and Society? *National Geographic Research* 6(1): 7-21.

Rice, Prudence

1987 *Pottery Analysis: A Source Book.* University of Chicago Press.

Shepard, Anna O.

1956 *Ceramics for the Archaeologist.* Publication 609, Carnegie Institution of Washington, Washington, D.C.

Steponaitis, Vincas, P.; M. James Blackman, and Hector Neff

1996 Large-Scale Patterns in the Chemical Composition of Mississippian Pottery. *American Antiquity,* 61(3): 555-572.

Wasserman, G.S.

1978. *Color Vision: An Historical Introduction.* New York: John Wiley and Sons.

Wyszecki, Gunter

1989 Color. *World Book Encyclopedia.*

Wyszecki, Gunter and W. S. Stiles

1982 *Color Science: Concepts and Methods, Quantitative Data and Formulae*. John Wiley and Sons, New York.

Figure 1. Representative spectra of colored particles on filter papers derived from the LI-COR spectroradiometer and the Colotron II color sensor. The Colotron II data are the average of three scans.

Table 1. Correlation (r, n = 52) between estimates of Munsell Color values determined by human observers with values derived using the spectroradiometer.

	Hue	Value	Chroma
Observer 1	.10	.81	.86
Observer 2	.22	.85	.77

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